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(54) **INSULATED NOTCH DESIGN FOR PIXELS IN AN ELECTROWETTING DEVICE**

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(51) **Int. Cl.**

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G02B 26/02	(2006.01)
G09G 3/34	(2006.01)
G02B 26/08	(2006.01)
G09G 3/28	(2013.01)

(52) **U.S. Cl.**
CPC ***G02B 26/005*** (2013.01); ***G02B 26/004*** (2013.01); ***G09G 3/348*** (2013.01); *G02B 26/08* (2013.01); *G02B 2207/115* (2013.01); *G09G 3/28* (2013.01); *G09G 3/3433* (2013.01); *G09G 2300/0426* (2013.01); *G09G 2300/0439* (2013.01); *G09G 2300/08* (2013.01)

(58) **Field of Classification Search**
CPC G02B 26/00; G02B 26/004; G02B 26/005; G02B 26/08; G02B 2207/115; G09G 3/28; G09G 3/34; G09G 3/3433; G09G 3/348; G09G 2300/0426; G09G 2300/0439; G09G 2300/08; G09G 2320/0252; G09G 2360/144; Y10T 29/49002
USPC 359/290, 291, 295, 298, 228, 245, 253; 345/60, 64, 204, 212, 214
See application file for complete search history.

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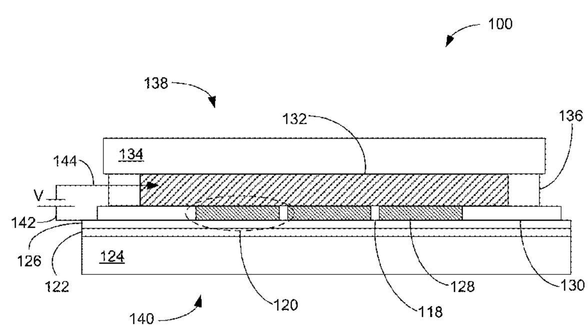
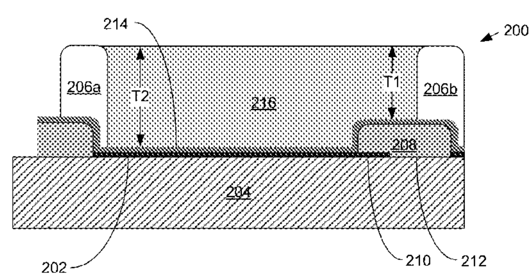
(57) **ABSTRACT**

Subject matter disclosed herein relates to arrangements and techniques that provide for controlling motion of an electrowetting oil within an electrowetting display device. An electrowetting display device comprises a substrate, an electrode on the substrate, a dielectric layer on a first portion of the electrode. The electrode extends along the substrate one of either entirely from a first end of a pixel area to a second end of the pixel area, or from the first end of the pixel area to the second end of the pixel area such that a portion of the substrate is an electrode free portion to thereby define a notch. A first fluid is disposed on a hydrophobic layer and a second fluid is disposed on the first fluid, the second fluid being immiscible with the first fluid. A dielectric constant of the dielectric layer is greater than a dielectric constant of the first fluid.

20 Claims, 5 Drawing Sheets





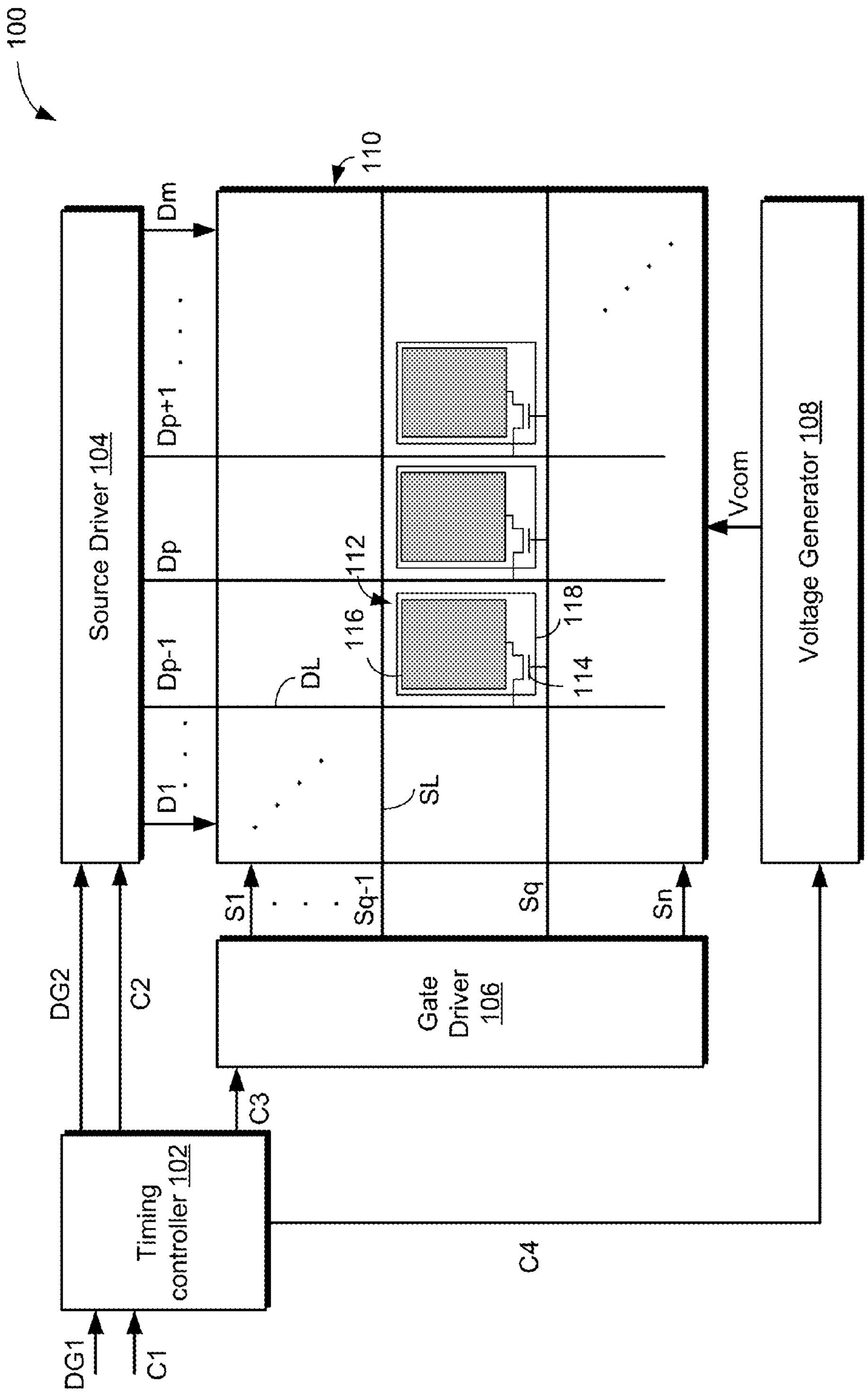

100
110
Source Driver 104
Dm
Dp+1
Dp
Dp-1
D1
DL
112
116
118
114
SL
S1
Sq-1
Sq
Sn
Vcom
Voltage Generator 108
Gate Driver 106
DG2
C2
C3
Timing controller 102
C4
DG1
C1

FIG. 1A

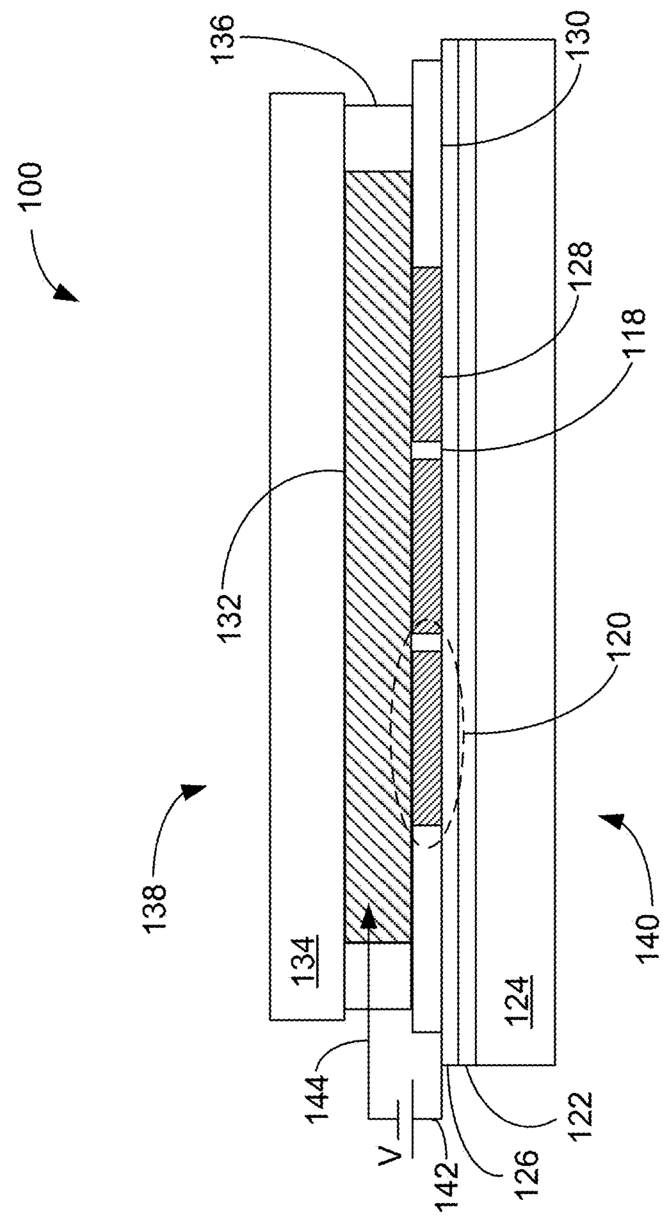


FIG. 1B

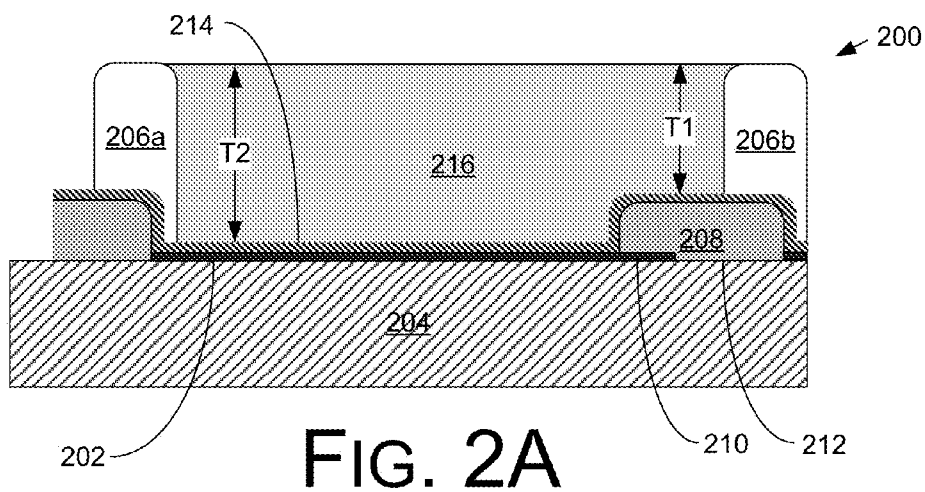


FIG. 2A

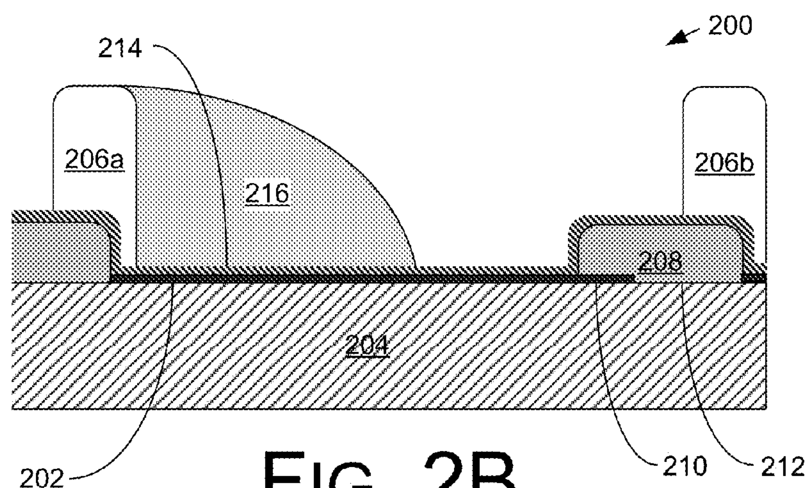


FIG. 2B

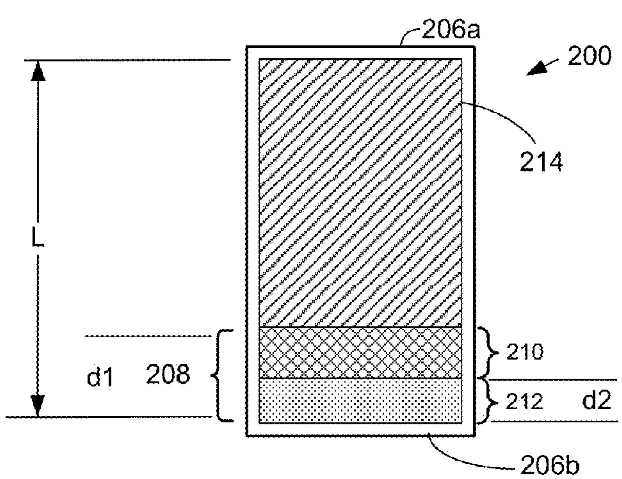
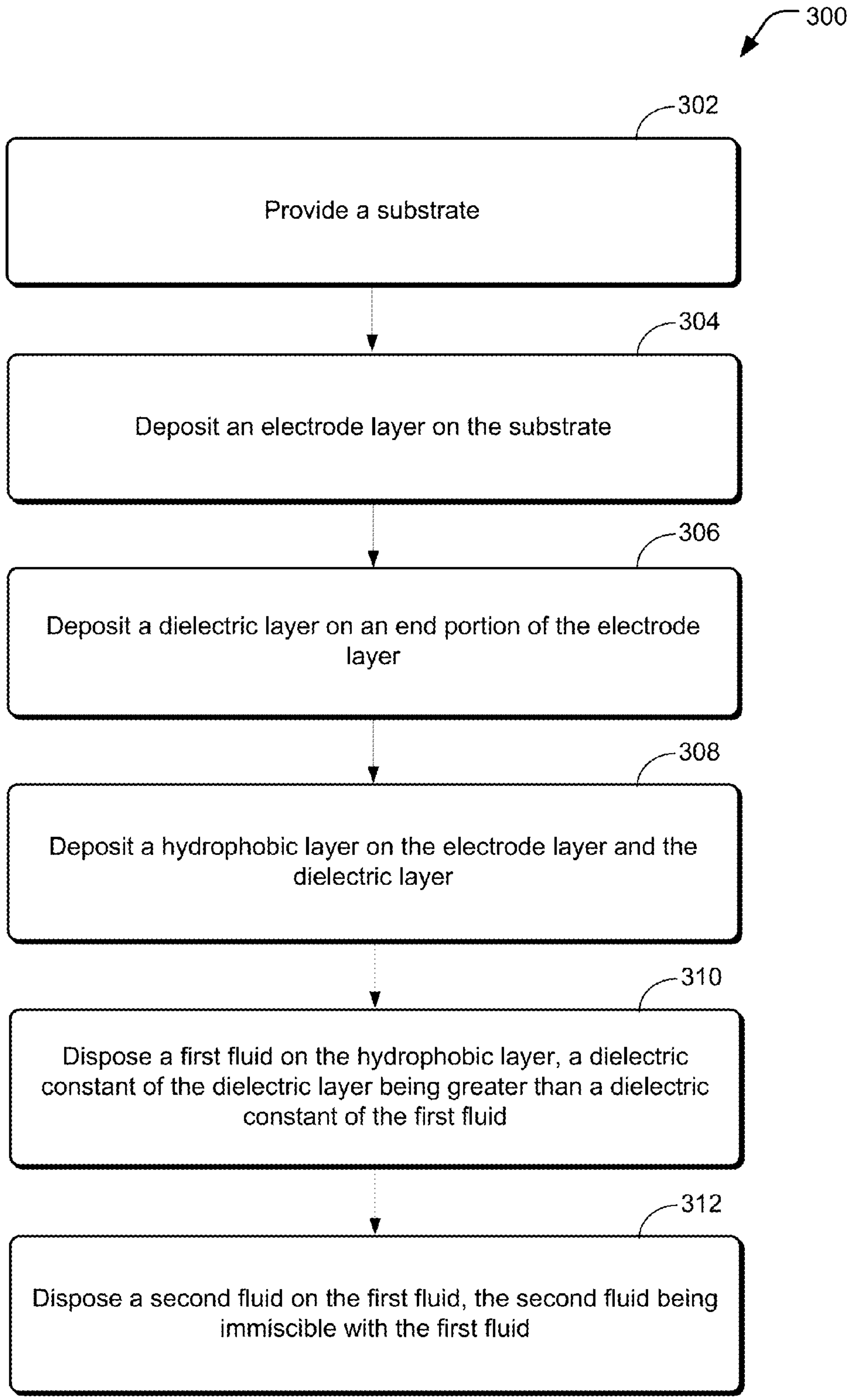


FIG. 2C



300
302
Provide a substrate
304
Deposit an electrode layer on the substrate
306
Deposit a dielectric layer on an end portion of the electrode layer
308
Deposit a hydrophobic layer on the electrode layer and the dielectric layer
310
Dispose a first fluid on the hydrophobic layer, a dielectric constant of the dielectric layer being greater than a dielectric constant of the first fluid
312
Dispose a second fluid on the first fluid, the second fluid being immiscible with the first fluid

FIG. 3

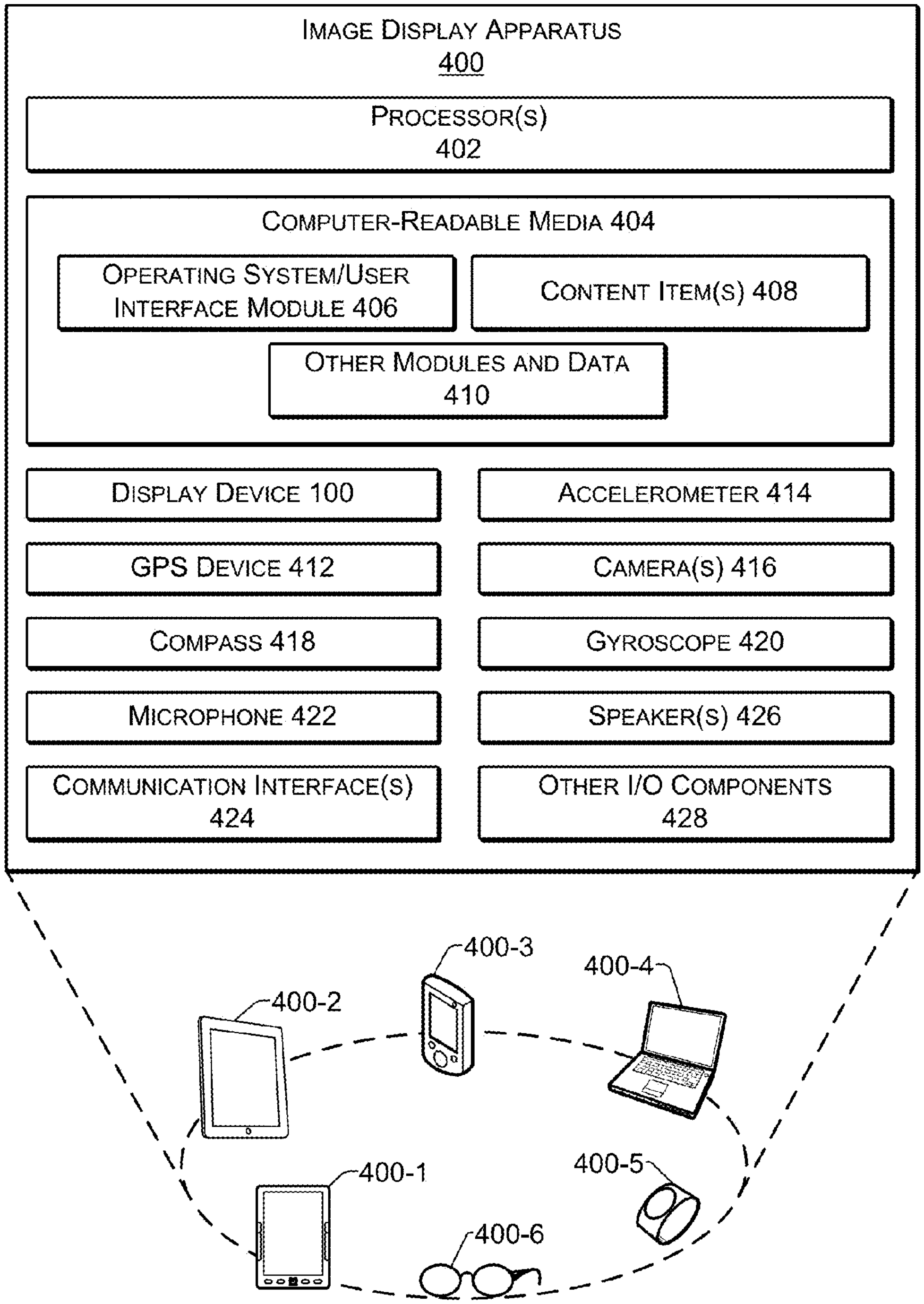


IMAGE DISPLAY APPARATUS
400
PROCESSOR(S)
402
COMPUTER-READABLE MEDIA 404
OPERATING SYSTEM/USER INTERFACE MODULE 406
CONTENT ITEM(S) 408
OTHER MODULES AND DATA
410
DISPLAY DEVICE 100
ACCELEROMETER 414
GPS DEVICE 412
CAMERA(S) 416
COMPASS 418
GYROSCOPE 420
MICROPHONE 422
SPEAKER(S) 426
COMMUNICATION INTERFACE(S)
424
OTHER I/O COMPONENTS
428
400-3
400-4
400-2
400-1
400-5
400-6

FIG. 4

INSULATED NOTCH DESIGN FOR PIXELS IN AN ELECTROWETTING DEVICE

BACKGROUND

Many portable electronic devices include displays for displaying various types of images. Examples of such displays include electrowetting displays (EWDs), liquid crystal displays (LCDs), electrophoretic displays (EPDs), light emitting diode displays (LED displays), etc. In EWD applications, a plurality of pixels (or sub-pixels) is defined between first and second substrates or support plates that are coupled together. The plurality of pixels is generally defined by pixel walls on the first substrate where each pixel includes electrowetting fluids. Each pixel is opened or closed based upon motion of the electrowetting fluids. With EWDs it is important to control the motion of the electrowetting fluids within the pixels in the same manner under all circumstances. Thus, it is important to have the pixels open and/or close in the same manner, i.e., to all open and/or close at the same or preferred opening point.

BRIEF DESCRIPTION OF THE DRAWINGS

The detailed description is described with reference to non-limiting and non-exhaustive embodiments illustrated in the accompanying figures. The same reference numerals in different figures refer to similar or identical items.

FIG. **1**A is a schematic view of an example of an electrowetting display device, according to various embodiments.

FIG. **1**B is a cross-section of a portion of the electrowetting display device of FIG. **1**A, according to some embodiments.

FIGS. **2**A and **2**B are simplified cross-sectional views of a portion of the electrowetting display device of FIGS. **1**A and **1**B including pixel walls.

FIG. **2**C is a simplified view of the layout of the portion of the electrowetting display device of FIGS. **2**A and **2**C.

FIG. **3** is a flowchart illustrating an example of a process of making an electrowetting display device.

FIG. **4** illustrates select components of an example image display apparatus that may include an electrowetting display device, according to various embodiments.

DETAILED DESCRIPTION

The present disclosure provides arrangements and techniques that provide for controlling motion of an electrowetting oil within an electrowetting display device.

In general, image display apparatuses, such as, for example, various electronic devices, including, but not limited to, portable computing devices, tablet computers, laptop computers, notebook computers, mobile phones, personal digital assistants (PDAs), and portable media devices (e.g., e-book devices, DVD players, etc.), display images on a display. Examples of such displays include, but are not limited to, LCDs, EWDs and EPDs.

More particularly, a display device, such as an electrowetting display device, for example, can be a thin film transistor electrowetting display (TFT-EWD) that generally includes an array of transmissive, reflective and/or transflective pixels configured to be operated by an active matrix addressing scheme. For example, rows and columns of pixels are operated by controlling voltage levels on a plurality of source lines and gate lines. In this fashion, the display device can produce an image by selecting particular pixels to transmit, reflect or block light. Pixels are addressed (e.g., selected) via rows and columns of the source lines and gate lines that are connected to transistors (e.g., used as switches) included in each pixel.

Transistors take up a relatively small fraction of the area of each pixel. For example, the transistor can be located underneath the reflector in reflective displays.

Electrically, the pixel is a small capacitor with a layer of insulating optical material (e.g., liquid crystal material or electrowetting material) sandwiched between two substrates, wherein each substrate generally includes a transparent conductive indium tin oxide (ITO) layer that each serves as an electrode. A one-way current-passing characteristic of the transistor of the pixel prevents charge that is being applied to the pixel from draining between refresh cycles of the display's image.

An electrowetting display employs an applied voltage to change the surface tension of a fluid in relation to a surface. For instance, by applying a voltage to a hydrophobic surface via a pixel electrode in conjunction with a common electrode, the wetting properties of the surface can be modified so that a fluid has a greater affinity for the surface. Hydrophobic generally refers to repelling water or polar fluids while hydrophilic generally refers to having an affinity for water or polar fluids. As one example of an electrowetting display, the modification of the surface energy by applying a voltage causes the electrolyte, considered to be the second fluid in an electrowetting fluid, in individual pixels of the display to adhere to the modified surface and thus, replace a colored oil layer, considered to be the first fluid in an electrowetting fluid, in individual pixels of the display. The electrowetting oil layer is generally made up of an oil that is electrically non-conductive and may for instance be an alkane like hexadecane or silicone oil. Thus, the electrowetting fluids in the individual pixels of the display responding to the change in surface tension act as an optical switch. When the voltage is absent, the colored electrowetting oil forms a continuous layer within a pixel, and the color may thus be visible to a user of the display. On the other hand, when the voltage is applied to the pixel, the colored electrowetting oil is displaced and the pixel becomes transparent. When multiple pixels of the display are independently activated, the display can present a color or grayscale image. The pixels may form the basis for a transmissive, reflective, or transmissive/reflective (transreflective) display. Further, the pixels may be responsive to high switching speeds (e.g., on the order of several milliseconds), while employing small pixel dimensions. Accordingly, the electrowetting displays herein may be suitable for applications such as displaying video and/or static content. In addition, the low power consumption of electrowetting displays in general makes the technology suitable for displaying content on portable display devices that rely on battery power.

In accordance with the various embodiments, each pixel includes a dielectric layer. The dielectric layer generally has a high dielectric constant that is greater than the dielectric constant of the electrowetting oil on the hydrophobic layer. The dielectric layer may comprise an organic material or an inorganic material. The dielectric layer is located at a portion of the pixel that is not close to the thin film transistor. The dielectric layer is located over the pixel electrode and under the hydrophobic layer. A portion of the dielectric layer is under the pixel wall, or at least in contact with the pixel wall. The presence of the dielectric layer means that the thickness of electrowetting oil on the dielectric layer is less than the thickness of electrowetting oil on the hydrophobic layer. In accordance with various embodiments, the pixel electrode does not extend all the way to the pixel wall under the dielectric layer to define a notch, i.e. an electrode free area. Thus, the dielectric layer is located on a portion of the pixel electrode and is also located on the notch, i.e., the portion of the substrate where the pixel electrode does not extend all the way to the pixel wall. Another dielectric layer or layers (not illustrated) may be located on the notch under the dielectric layer. Such dielectric layer(s) may generally not have a high dielectric constant in comparison to the electrowetting oil. Thus, an "insulated notch" is defined by the notch in conjunction with the portion of the dielectric layer over the notch. The fringe electric field effect is greater due to the presence of the end of the pixel electrode in conjunction with the substrate. Due to the greater fringe electric field effect and the thinness of the electrowetting oil on the dielectric layer the pixel will tend to open at the dielectric layer more consistently and accurately. Accordingly, the pixels will all generally have a similar manner of movement of the electrowetting oil from the dielectric layer towards the opposite end of the pixel away from the notch, although the direction of movement of the electrowetting oil within some or all of the pixels may be designed to be different.

Referring to FIG. **1**A, an example of an electrowetting display device **100** is schematically illustrated that includes a timing controller **102**, a source driver (data driver) **104**, a gate driver (scan driver) **106**, a voltage generator **108**, and an electrowetting display panel **110**. The electrowetting display panel **110** is driven by the timing controller **102**, the source driver **104**, the gate driver **106**, and the voltage generator **108**.

As an example of general operation of the electrowetting display device **100**, responsive to a first data signal DG**1** and a first control signal C**1** from an external source, e.g., a graphic controller (not illustrated), the timing controller **102** applies a second data signal DG**2** and a second control signal C**2** to the source driver **104**; a third control signal C**3** to the gate driver **106**; and a fourth control signal C**4** to the voltage generator **108**.

The source driver **104** converts the second data signal DG**2** to voltages, i.e., data signals, and applies the data signals D**1**, . . . , Dp−1, Dp, Dp+1, . . . , Dm to the electrowetting display panel **110**. The gate driver **106** sequentially applies scan signals S**1**, . . . , Sq−1, Sq, . . . , Sn to the electrowetting display panel **110** in response to the third control signal C**3**.

The voltage generator **108** applies a common voltage Vcom to the electrowetting display panel **110** in response to the fourth control signal C**4**. Although not illustrated in FIG. **1**A, the voltage generator **108** generates various voltages required by the timing controller **102**, the source driver **104**, and the gate driver **106**.

The electrowetting display panel **110** includes m data lines D, i.e., source lines, to transmit the data voltages and n gate lines S, i.e., scan lines, to transmit a gate-on signal.

Pixel areas **112** are positioned adjacent to crossing points of the data lines D and the gate lines S crossing the data lines D and thus are arranged in a grid of rows and columns. Each pixel area **112** includes a hydrophobic surface (not illustrated in FIG. **1**A), and a thin film transistor **114** and a pixel electrode **116** under the hydrophobic surface. Each pixel area **112** may also include a storage capacitor (not illustrated) under the hydrophobic surface. A pixel wall **118** defines the pixel area **112**. Pixel areas **112** can represent pixels within the electrowetting display device **100** or sub-pixels within the electrowetting display device **100**, depending upon the application for the electrowetting display device **100**.

FIG. **1**B is a cross-section of a portion of the electrowetting display device **100** illustrating several electrowetting elements **120** that generally correspond to pixel areas **112**, according to some embodiments. An electrode layer **122** that includes the pixel electrodes **116** (not illustrated in FIG. **1**B) is formed on a bottom substrate or support plate **124**. The electrode layer **122** generally comprises indium tin oxide (ITO). In some implementations, a dielectric barrier layer (not illustrated) may at least partially separate the electrode layer **122** from a hydrophobic layer **126** also formed on the bottom substrate **124** over the electrode layer **122**. In some implementations, the hydrophobic layer **126** can comprise a fluoropolymer, such as, for example, AF1600, produced by DuPont, based in Wilmington, Del. The pixel walls **118** form a patterned electrowetting element grid on the hydrophobic layer **126**, as can be seen in FIG. **1**A. The pixel walls **118** may comprise a photoresist material, such as, for example, epoxy-based negative photoresist SU-8. The patterned electrowetting element grid comprises rows and columns that form an electrowetting element array (e.g., electrowetting display panel **110**) of field electrowetting elements and border electrowetting elements. For example, an electrowetting element can have a width and length in a range of about 50 to 500 microns. A first fluid **128**, which can have a thickness in a range of about 1 to 10 microns, for example, overlies the hydrophobic layer **126**. The first fluid **128** is generally an electrowetting oil and is partitioned by the pixel walls **118** of the patterned electrowetting element grid. An outer rim **130** can comprise the same material as the pixel walls **118**. A second fluid **132**, such as a fluid that includes an electrolyte, overlies the electrowetting oil **128** and the pixel walls **118** of the patterned electrowetting element grid.

The second fluid **132** is immiscible with the first fluid **128**. Generally, immiscible refers to the inability of the second fluid **132** to mix or blend with the first fluid **128**. The second fluid **132** generally includes an electrolyte and is electrically conductive or polar and thus, is generally an electroconductive or polar liquid. The second fluid **132** may be water or a salt solution such as a solution of potassium chloride in a mixture of water and ethyl alcohol, for example.

The second fluid **132** is preferably transparent, but may be colored, absorbing. The first fluid **128**, generally referred to as electrowetting oil, is electrically non-conductive and may for instance be an alkane like hexadecane or (silicone) oil. The hydrophobic layer **126** is arranged on the bottom substrate **124** to create an electrowetting surface area. The hydrophobic character causes the first fluid **128** to adhere preferentially to the bottom substrate **124** since the first fluid **128** has a higher wettability with respect to the surface of the hydrophobic layer **126** than the second fluid **132**. Wettability relates to the relative affinity of a fluid for the surface of a solid. Wettability increases with increasing affinity, and it can be measured by the contact angle formed between the fluid and the solid and measured internal to the fluid of interest. For example, such a contact angle can increase from relative non-wettability of more than 90° to complete wettability at 0°, in which case the fluid tends to form a film on the surface of the solid.

A top substrate or support plate **134** covers the second fluid **132** and an adhesive/sealing material **136** retains the second fluid **132** over the electrowetting element array. The adhesive/sealing material **136** generally comprises ultraviolet (UV) curable epoxy glue, although other types of adhesive/sealing material are acceptable. The bottom substrate **124** and the top substrate **134** may be separate parts of individual electrowetting elements or the bottom substrate **124** and the top substrate **134** may be shared by a plurality of electrowetting elements. The bottom substrate **124** and the top substrate **134** may be made of glass or polymer and may be rigid or flexible, for example.

A voltage V applied across the second fluid **132** and the dielectric barrier layer stack (e.g., the hydrophobic layer **126**) of individual electrowetting elements can control transmittance or reflectance of the individual electrowetting elements.

The electrowetting display device **100** has a viewing side **138** on which an image for display formed by the electrowetting display device **100** can be viewed, and a rear side **140**. The top substrate **134** faces viewing side **138** and the bottom substrate **124** faces the rear side **140**. The top substrate **134** is coupled to the bottom substrate **124** with the adhesive/sealing material **136**. In an alternative embodiment, the electrowetting display device **100** may be viewed from the rear side **140**. The electrowetting display device **100** may be a reflective, transmissive or transreflective type. The electrowetting display device **100** may be a segmented display type in which the image is built up of segments. The segments can be switched simultaneously or separately. Each segment includes one electrowetting element **120** or a number of electrowetting elements **120** that may be neighboring or distant from one another. The electrowetting elements **120** included in one segment are switched simultaneously, for example. The electrowetting display device **100** may also be an active matrix driven display type or a passive matrix driven display, just to name a few examples.

The electrode layer **122** is separated from the first fluid **128** and the second fluid **132** by an insulator, which may be the hydrophobic layer **126**. The electrode layer **122** (and thereby the pixel electrodes **116**) is supplied with voltage signals V by a first signal line **142** as will be further described herein. A second signal line **144** is electrically connected to an electrode (not illustrated in FIG. **1**B) that generally corresponds to the common electrode previously mentioned that is in contact with the conductive second fluid **132**. Thus, this electrode may be common to more than one electrowetting element **120** since the electrowetting elements **120** are generally fluidly interconnected by and share the second fluid **132** uninterrupted by the pixel walls **118**. However, even in an embodiment where the pixel walls **118** extend to the top substrate **134**, the electrode may be common to more than one electrowetting element **120**. In such an embodiment, the second fluid **132** might not be shared where the pixel walls **118** surround each pixel area **112** without openings in the pixel walls through which the second fluid **132** may flow. The electrowetting elements **120** are controlled by the voltage V applied between the first and second signal lines **142** and **144**.

The first fluid **128** absorbs at least a part of the optical spectrum. The first fluid **128** may be transmissive for a part of the optical spectrum, forming a color filter. For this purpose, the first fluid **128** may be colored by addition of pigment particles or dye, for example. Alternatively, the first fluid **128** may be black (e.g., absorbing substantially all parts of the optical spectrum) or reflecting. The hydrophobic layer **126** may be transparent or reflective. A reflective layer may reflect the entire visible spectrum, making the layer appear white, or part of it, making it have a color.

When the voltage V applied between the signal lines **142** and **144** is set at a non-zero active signal level, the electrowetting element **120** will enter into an active state. Electrostatic forces will move the second fluid **132** toward the electrode layer **122**, thereby repelling the first fluid **128** from the area of the hydrophobic layer **126** to the pixel walls **118** surrounding the area of the hydrophobic layer **126**, to a droplet-like shape. This action uncovers the first fluid **128** from the surface of the hydrophobic layer **126** of the electrowetting element **120**. When the voltage across the electrowetting element **120** is returned to an inactive signal level of zero volts or a value near to zero volts, the electrowetting element **120** will return to an inactive state, where the first fluid **128** flows back to cover the hydrophobic layer **126**. In this way, the first fluid **128** forms an electrically controllable optical switch in each electrowetting element **120**.

Generally, the thin film transistor **114** includes a gate electrode that is electrically connected to a corresponding scan line of the scan lines S, a source electrode that is electrically connected to a corresponding data line (e.g., first signal line **142** of FIG. **1**B) of the data lines D, and a drain electrode that is electrically connected to the pixel electrode **116**. Thus, the pixel areas **112** are operated, i.e. driving of the electrowetting display device **100**, based upon the scan lines S and the data lines D of FIG. **1**A.

FIG. **2**A is a simplified cross-sectional view of a pixel area **200**, which generally corresponds to a pixel area **112** of FIGS. **1**A and **1**B. An electrode layer **202** (which generally corresponds to the electrode layer **122** of FIG. **1**B) is located on a substrate **204** (which generally corresponds to bottom substrate **124** of FIG. **1**B). In accordance with various embodiments, the electrode layer **202** extends from one pixel wall **206***a* towards a second pixel wall **206***b* (which generally correspond to the pixel walls **118** of FIGS. **1**A and **1**B).

In accordance with various embodiments, the electrode layer **202** does not fully extend to the second pixel wall **206***b*. A dielectric layer **208** is provided at the end of the pixel area **200** that is adjacent to the second pixel wall **206***b*. As can be seen, the dielectric layer **208** is located directly on a portion **210** of the electrode layer **202** and is also located directly on a portion **212** of the substrate **204**. However, in embodiments, there may be other layers on the substrate **204** between dielectric layer **208** and portion **212** of the substrate **204**. The portion **212** generally defines a notch under the dielectric layer **208** from the end of the electrode layer **202** to the pixel walls **206***b*. A hydrophobic layer **214** (which generally corresponds to the hydrophobic layer **126** of FIG. **1**B) is located on the electrode layer **202** and the dielectric layer **208**. The pixel walls **206***a*, **206***b* are located on the hydrophobic layer **214**. However, in embodiments, the hydrophobic layer **214** may not extend under the pixel walls **206***a*, **206***b* but rather may extend between the pixel walls **206***a*, **206***b*. The first pixel wall **206***a* is generally located adjacent to the thin film transistor **114** of FIG. **1**A (not illustrated in FIG. **2**A). Thus, the thin film transistor **114** is generally located away from dielectric layer **208**. It does not necessarily need to be located adjacent to the first pixel wall **206***a* but rather generally away from the dielectric layer **208**. An electrowetting oil **216** (generally corresponding to the first fluid **128** of FIG. **1**B) is located on the hydrophobic layer **214**. Thus, as can be seen in FIG. **2**A, the presence of the dielectric layer **208** means that the thickness T1 of electrowetting oil **216** on the dielectric layer **208** is less than the thickness T2 of electrowetting oil **216** on the hydrophobic layer **214**. In accordance with various embodiments, the dielectric layer **208** generally has a high dielectric constant that is greater than the dielectric constant of the electrowetting oil **216**. For example, a dielectric constant of the dielectric layer **208** may be approximately 8 while the dielectric constant of the electrowetting oil **216** is approximately 2.5. This is only an example and is not meant to be limiting. As noted, the dielectric layer **208** has a dielectric constant that is greater than the dielectric constant of the electrowetting oil **216**.

Referring to FIG. **2**B, when voltage is applied to the pixel area **200** as previously described herein, the wetting properties of the surface of the hydrophobic layer **214** are modified so that the second fluid **132** (not illustrated in FIGS. **2**A and **2**B) has a greater affinity for the surface of the hydrophobic layer **214**. Such modification causes the electrowetting oil **216** to "break" and move towards the pixel wall **206***a* at the opposite end of the pixel area **200** away from the dielectric layer **208**. The second fluid **132** that includes the electrolyte becomes attracted to the hydrophobic layer **214** and generally displaces the electrowetting oil **216**, as previously described. Thus, the pixel area **200** "opens" from the dielectric layer **208** towards the second pixel wall **206***a*.

FIG. **2**C is a simplified view of the layout of the pixel area **200** illustrated in FIGS. **2**A and **2**B, without the electrowetting oil **216**. As can be seen, the dielectric layer **208** extends across the width of the pixel area **200** adjacent to the pixel wall **206***b* and will generally extend continuously across adjacent pixel areas **200** (not illustrated), as will the hydrophobic layer **214**. In accordance with the various embodiments the pixel area **200** has a substantially rectangular shape and can have a width and length in the range of about 50 to 500 micrometers. However, in other embodiments, the pixel area **200** may have a more square shape, a more triangular shape, a more circular shape, etc. depending on desired motion of the electrowetting oil **216**. The dielectric layer **208** generally has a thickness in a range of approximately 0.5 to 1.5 micrometers and extends a distance d**1** that is approximately twenty percent of the length L of the pixel area **200** from the second pixel wall **206***b* towards the first pixel wall **206***a*. Merely as an example, the dielectric layer **208** has a thickness of approximately 1 micrometer for a pixel wall **206***b* having a height of approximately 3 micrometers. In general, the thickness of the dielectric layer **208** is related to the difference between the dielectric constant of the dielectric layer **208** and the dielectric of the electrowetting oil **216**. Generally, the greater the difference, then the thickness of the dielectric layer **208** may be smaller. The portion **212** of the substrate **204** generally extends from the second pixel wall **206***b* towards the first pixel wall **206***a* a distance d**2** that is up to approximately fifteen percent of the length L of the pixel area **200**. Thus, the electrode layer **202** extends from a first portion of the substrate **204** to a second portion of the substrate **204** such that the second portion of the substrate is an electrode free portion to thereby define a notch (etched away portion **212**).

In order to create the pixel area **200** of FIGS. **2**A-**2**C, the electrode layer **202**, which generally consists of a substance or material such as indium tin oxide (ITO) is deposited on the substrate **204**. If the portion **212** of the substrate **204** is desired, then the portion **212** is created by etching away a portion of the electrode layer **202**. The dielectric layer **208** is then deposited over the end portion **210** of the electrode layer **202** and any etched-away portion **212** of the electrode layer **202** on the substrate **204**. The hydrophobic layer **214** is then deposited on the electrode layer **202** and the dielectric layer **208**. The pixel walls **206** are deposited on the hydrophobic layer **214**. The electrowetting oil **216** can then be deposited on the hydrophobic layer **214**. Alternatively, the pixel walls **206** can be deposited before the hydrophobic layer **214** and dielectric layer **208** are deposited. In such an embodiment, the pixel walls **206** will be in contact with the hydrophobic layer **214** and the dielectric layer **208** as opposed to on the hydrophobic layer **214** and the dielectric layer **208**. A top substrate (not illustrated in FIGS. **2**A-**2**C), is then placed over the substrate **204** by, for example, a roll coupling method or an air film coupling method. Generally, the second fluid **132** (not illustrated in FIGS. **2**A-**2**C) is provided and filled between the substrates at approximately the same time that the top substrate is coupled to the substrate **204**. The two substrates can be fixed by using a heat or UV curable adhesive.

Thus, any etched-away portion **212** of the electrode layer **202** on the substrate **204** provides an "insulated notch" that is defined by the dielectric layer **208** and the etched-away portion **212**, i.e. the dielectric layer **208** insulates the portion **212**. The location of the end of the electrode layer **202** at the etched away portion **212** on the substrate **204** results in the electric field at that end of the electrode layer **202** being stronger due to the fringe field effect. As is known, with the fringe field effect, if one has two parallel plates forming a capacitor, the electric field does not end abruptly at the edge of the plates. There is some field outside the plates that curves from one plate to the other plate. Thus, there is more electric field present because of the fringe fields. Additionally, due to the higher dielectric constant of the dielectric layer **208** in comparison to the electrowetting oil **216**, the voltage drop within the pixel area **200** is greater over the dielectric layer **208**. Generally, the voltage drop realized over the dielectric layer **208** is inversely proportional to the dielectric constant of the dielectric layer **208**. In response to voltage applied to the pixel area **200**, the greater fringe electric field effect and the voltage drop at the thin layer of the electrowetting oil **216** on the dielectric layer **208** causes the electrowetting oil **216** to break away from the dielectric layer **208** to thereby open the pixel area **200**. Thus, in accordance with various embodiments, the pixel area **200** generally opens more consistently and accurately. Accordingly, the pixel areas **200** will all generally act in a similar manner as far as movement of the electrowetting oil **216** from the dielectric layer **208** towards the pixel wall **206***a*.

FIG. **3** is a flowchart illustrating a process **300** of an example of making an electrowetting display device, for example an electrowetting display device as described in FIGS. **1**A, **1**B, **2**A, **2**B and **2**C. At **302**, a substrate is provided. At **304**, an electrode layer is deposited on the substrate. At **306**, a dielectric layer is deposited on an end portion of the electrode layer. At **308**, a hydrophobic layer is deposited on the electrode layer and the dielectric layer. At **310**, a first fluid is disposed on the hydrophobic layer, a dielectric constant of the dielectric layer being greater than a dielectric constant of the first fluid. At **312**, a second fluid is disposed on the first fluid, the second fluid being immiscible with the first fluid.

FIG. **4** illustrates select example components of an example image display apparatus **400** that may be used with the electrowetting display device **100** according to some implementations. Other types of displays may also be used with the example image display apparatus **400**. Such types of displays include, but are not limited to, LCDs, cholesteric displays, electrophoretic displays, electrofluidic pixel displays, photonic ink displays, and the like.

The image display apparatus **400** may be implemented as any of a number of different types of electronic devices. Some examples of the image display apparatus **400** may include digital media devices and eBook readers **400-1**; tablet computing devices **400-2**; smart phones, mobile devices and portable gaming systems **400-3**; laptop and netbook computing devices **400-4**; wearable computing devices **400-5**; augmented reality devices, helmets, goggles or glasses **400-6**; and any other device capable of connecting with the electrowetting display device **100** and including a processor and memory for controlling the display according to the techniques described herein.

In a very basic configuration, the image display apparatus **400** includes, or accesses, components such as at least one control logic circuit, central processing unit, or processor **402**, and one or more computer-readable media **404**. Each processor **402** may itself comprise one or more processors or processing cores. For example, the processor **402** can be implemented as one or more microprocessors, microcomputers, microcontrollers, digital signal processors, central processing units, state machines, logic circuitries, and/or any devices that manipulate signals based on operational instructions. In some cases, the processor **402** may be one or more hardware processors and/or logic circuits of any suitable type specifically programmed or configured to execute the algorithms and processes described herein. The processor **402** can be configured to fetch and execute computer-readable instructions stored in the computer-readable media **404** or other computer-readable media. The processor **402** can perform one or more of the functions attributed to the timing controller **102**, the source or data driver **104**, and/or the gate or scan driver **106** of the electrowetting display device **100**. The processor **402** can also perform one or more functions attributed to a graphic controller (not illustrated) for the electrowetting display device.

Depending on the configuration of the image display apparatus **400**, the computer-readable media **404** may be an example of tangible non-transitory computer storage media and may include volatile and nonvolatile memory and/or removable and non-removable media implemented in any type of technology for storage of information such as computer-readable instructions, data structures, program modules or other data. The computer-readable media **404** may include, but is not limited to, RAM, ROM, EEPROM, flash memory or other computer-readable media technology, CD-ROM, digital versatile disks (DVD) or other optical storage, magnetic cassettes, magnetic tape, solid-state storage and/or magnetic disk storage. Further, in some cases, the image display apparatus **400** may access external storage, such as RAID storage systems, storage arrays, network attached storage, storage area networks, cloud storage, or any other medium that can be used to store information and that can be accessed by the processor **402** directly or through another computing device or network. Accordingly, the computer-readable media **404** may be computer storage media able to store instructions, modules or components that may be executed by the processor **402**.

The computer-readable media **404** may be used to store and maintain any number of functional components that are executable by the processor **402**. In some implementations, these functional components comprise instructions or programs that are executable by the processor **402** and that, when executed, implement operational logic for performing the actions attributed above to the image display apparatus **400**. Functional components of the image display apparatus **400** stored in the computer-readable media **404** may include the operating system and user interface module **406** for controlling and managing various functions of the image display apparatus **400**, and for generating one or more user interfaces on the electrowetting display device **100** of the image display apparatus **400**.

In addition, the computer-readable media **404** may also store data, data structures and the like, that are used by the functional components. For example, data stored by the computer-readable media **404** may include user information and, optionally, one or more content items **408**. Depending on the type of the image display apparatus **400**, the computer-readable media **404** may also optionally include other functional components and data, such as other modules and data **410**, which may include programs, drivers and so forth, and the data used by the functional components. Further, the image display apparatus **400** may include many other logical, programmatic and physical components, of which those described are merely examples that are related to the discussion herein. Further, while the figures illustrate the functional components and data of the image display apparatus **400** as being present on the image display apparatus **400** and executed by the processor **402** on the image display apparatus **400**, it is to be appreciated that these components and/or data may be distributed across different computing devices and locations in any manner.

FIG. **4** further illustrates examples of other components that may be included in the image display apparatus **400**. Such examples include various types of sensors, which may include a GPS device **412**, an accelerometer **414**, one or more cameras **416**, a compass **418**, a gyroscope **420**, a microphone **422**, and so forth.

The image display apparatus **400** may further include one or more communication interfaces **424**, which may support both wired and wireless connection to various networks, such as cellular networks, radio, Wi-Fi networks, close-range wireless connections, near-field connections, infrared signals, local area networks, wide area networks, the Internet, and so forth. The communication interfaces **424** may further allow a user to access storage on or through another device, such as a remote computing device, a network attached storage device, cloud storage, or the like.

The image display apparatus **400** may further be equipped with one or more speakers **426** and various other input/output (I/O) components **428**. Such I/O components **428** may include a touchscreen and various user controls (e.g., buttons, a joystick, a keyboard, a keypad, etc.), a haptic or tactile output device, connection ports, physical condition sensors, and so forth. For example, the operating system **406** of the image display apparatus **400** may include suitable drivers configured to accept input from a keypad, keyboard, or other user controls and devices included as the I/O components **428**. Additionally, the image display apparatus **400** may include various other components that are not illustrated, examples of which include removable storage, a power source, such as a battery and power control unit, a PC Card component, and so forth.

Various instructions, methods and techniques described herein may be considered in the general context of computer-executable instructions, such as program modules stored on computer storage media and executed by the processors herein. Generally, program modules include routines, programs, objects, components, data structures, etc., for performing particular tasks or implementing particular abstract data types. These program modules, and the like, may be executed as native code or may be downloaded and executed, such as in a virtual machine or other just-in-time compilation execution environment. Typically, the functionality of the program modules may be combined or distributed as desired in various implementations. An implementation of these modules and techniques may be stored on computer storage media or transmitted across some form of communication.

Although the subject matter has been described in language specific to structural features and/or methodological acts, it is to be understood that the subject matter defined in the appended claims is not necessarily limited to the specific features or acts described. Rather, the specific features and acts are disclosed as illustrative forms of implementing the claims.

One skilled in the art will realize that a virtually unlimited number of variations to the above descriptions are possible, and that the examples and the accompanying figures are merely to illustrate one or more examples of implementations.

It will be understood by those skilled in the art that various other modifications can be made, and equivalents can be substituted, without departing from claimed subject matter. Additionally, many modifications can be made to adapt a particular situation to the teachings of claimed subject matter without departing from the central concept described herein. Therefore, it is intended that claimed subject matter not be limited to the particular embodiments disclosed, but that such claimed subject matter can also include all embodiments falling within the scope of the appended claims, and equivalents thereof.

In the detailed description above, numerous specific details are set forth to provide a thorough understanding of claimed subject matter. However, it will be understood by those skilled in the art that claimed subject matter can be practiced without these specific details. In other instances, methods, devices, or systems that would be known by one of ordinary skill have not been described in detail so as not to obscure claimed subject matter.

Reference throughout this specification to "one embodiment" or "an embodiment" can mean that a particular feature, structure, or characteristic described in connection with a particular embodiment can be included in at least one embodiment of claimed subject matter. Thus, appearances of the phrase "in one embodiment" or "an embodiment" in various places throughout this specification are not necessarily intended to refer to the same embodiment or to any one particular embodiment described. Furthermore, it is to be understood that particular features, structures, or characteristics described can be combined in various ways in one or more embodiments. In general, of course, these and other issues can vary with the particular context of usage. Therefore, the particular context of the description or the usage of these terms can provide helpful guidance regarding inferences to be drawn for that context.

What is claimed is:

1. An electrowetting display device comprising a first substrate and a second substrate opposite to the first substrate, wherein the first substrate and the second substrate define a plurality of pixel areas, wherein each pixel area comprises:

an electrode on the first substrate, wherein the electrode extends along a top surface of the first substrate from a first end of the pixel area to an opposing second end of the pixel area such that a portion of the first substrate is an electrode free portion and the electrode free portion defines a notch;

an organic material disposed on the notch and on a first portion of the electrode proximate to the notch;

a hydrophobic layer on a second portion of the electrode and on the organic material;

an electrowetting oil on the hydrophobic layer and a fluid that includes an electroconductive or polar liquid on the electrowetting oil; and

a thin film transistor coupled to the electrode and a voltage source,

wherein the organic material has a dielectric constant higher than a dielectric constant of the electrowetting oil.

2. The electrowetting display device of claim **1**, wherein a first portion of the organic material is directly on the first portion of the electrode and a second portion of the organic material is directly on the notch.

3. An electrowetting display device comprising:

a substrate;

an electrode layer on the substrate;

a dielectric layer disposed on an end portion of the electrode layer;

a hydrophobic layer on the electrode layer and the dielectric layer;

a first fluid disposed on the hydrophobic layer; and

a second fluid disposed on the first fluid, the second fluid being immiscible with the first fluid,

wherein a dielectric constant of the dielectric layer is greater than a dielectric constant of the first fluid.

4. The electrowetting display device of claim **3**, wherein the electrode layer covers a first portion of the substrate and a second portion of the substrate defines a notch, and wherein the dielectric layer is disposed on the end portion of the electrode layer and the notch.

5. The electrowetting display device of claim **4**, wherein the notch has a width substantially equal to a width of a pixel area defined on the substrate and a length in a range of up to fifteen percent of a length of the pixel area.

6. The electrowetting display device of claim **5**, wherein the notch has a length of approximately fifteen percent of the length of the pixel area.

7. The electrowetting display device of claim **3**, wherein the dielectric layer has a width substantially equal to a width of a pixel area defined on the substrate, a length in a range of up to twenty percent of a length of the pixel area and a thickness in a range of 0.5 to 1.5 micrometers.

8. The electrowetting display device of claim **3**, wherein the dielectric constant of the dielectric layer is in a range of between 7 and 9 and the dielectric constant of the first fluid is in a range of between 2 and 3.

9. The electrowetting display device of claim **3**, further comprising a thin film transistor located at the first portion of the substrate.

10. The electrowetting display device of claim **3**, wherein the electrowetting display device is included within an electronic device.

11. The electrowetting display device of claim **3**, wherein the first fluid comprises an electrowetting oil and the second fluid comprises a fluid that includes an electroconductive or polar liquid.

12. The electrowetting display device of claim **3**, wherein the dielectric layer comprises an organic material.

13. The electrowetting display device of claim **3**, wherein the dielectric layer comprises an inorganic material.

14. A method of making an electrowetting device, the method comprising:

providing a substrate;

depositing an electrode layer on the substrate;

depositing a dielectric layer on an end portion of the electrode layer;

depositing a hydrophobic layer on the electrode layer and the dielectric layer;

disposing a first fluid on the hydrophobic layer; and

disposing a second fluid on the first fluid, the second fluid being immiscible with the first fluid,

wherein a dielectric constant of the dielectric layer is greater than a dielectric constant of the first fluid.

15. The method of claim **14**, further comprising:

prior to depositing the dielectric layer on the end portion of the electrode layer, removing a portion of the electrode layer to create a notch,

wherein depositing the dielectric layer comprises depositing the dielectric layer such that a first portion of the dielectric layer is disposed on the end portion of the electrode layer and a second portion of the dielectric layer is disposed on the notch.

16. The method of claim **15**, wherein the notch has a width substantially equal to a width of a pixel area defined on the substrate and a length in a range of up to fifteen percent of a length of the pixel area.

17. The method of claim **15**, further comprising providing a thin film transistor located away from the end portion of the electrode layer.

18. The method of claim **14**, wherein the dielectric layer has a width substantially equal to a width of a pixel area defined on the substrate, a length in a range of up to twenty percent of a length of the pixel area and a thickness in a range of 0.5 to 1.5 micrometers.

19. The method of claim **14**, wherein the dielectric constant of the dielectric layer is in a range of 7-9 and the dielectric constant of the first fluid is in a range of 2-3.

20. The method of claim **14**, wherein the first fluid comprises an electrowetting oil and the second fluid comprises a fluid that includes an electroconductive or polar liquid.

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